ENERGY EFFICIENT PRACTICES, PRODUCTS AND PROGRAMS FOR BUILDINGS

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INTRODUCTION

Energy conservation protects the environment and saves money. The United States have achieved outstanding results so far in energy conservation and efficiency since the oil crises in the 1970's. Yet there are enormous opportunities available in the building industry to further reduce energy usage with the technologies that are available today. This report discusses the different building related energy conservation strategies that can be implemented, examines some of the energy efficient building products, equipment and appliances that are currently available for home and commercial use, and provides operation and maintenance tips.

One of the most promising energy efficient practice and product is the photovoltaic technology, which is discussed in chapter 3. Not only is solar energy a sustainable resource and environmentally friendly, it could generate excess energy to feed back into the electric grid system and result in no energy charges for the owner other than the initial installation cost. Finally, this report will examine the EPA Energy Star Buildings and Green Lights program and the Energy Star labeled products intended to encourage the growth and use of energy efficient technologies and practices.

Besides the economic advantages of reduced energy consumption, energy efficient buildings and appliances will help set the world on the path to sustainable growth and reduce the emission of greenhouse gases that contribute to global warming and possible catastrophic climate changes.

Energy efficiency is an important consideration in the design and operation of any building. Buildings in the U.S., both residential and commercial, use about 29 quadrillion BTU's (quads) of energy each year and account for 35% of total energy consumption.[1] In the commercial and industrial sector alone, the Environmental Protection Agency estimates that businesses spend $110 billion each year to power buildings and $25 billion of that is wasted due to inefficiency.[2] With such a large load and high inefficiency, the savings can be substantial. It is estimated that residential and commercial energy use can be cut an additional 25 to 50 percent using technology available today.[3]

The costs associated with energy consumption affects everyone from an apartment dweller, to homeowner, to public and private facility managers, to corporate executives. However, there's a general lack of awareness of energy efficient possibilities amongst the public. One might ask what are the possibilities? Are they cost effective? What are some of the energy efficient practices, products and programs that encourage energy efficiency currently available?

CHAPTER ONE
ENERGY EFFICIENT PRACTICES

The best time to incorporate energy efficient practices into a building is during the design phase. The decisions made during the design phase will have a lasting affect on the building for decades to come. The strategy should be to view the building as a whole integrated system rather than a series of independent components. Incorporating this strategy into the designing, planning, and building stages will bear significant energy efficiency. The different products and technologies such as lighting, windows and mechanical systems can be integrated together and create a synergistic effect to save on construction and operating costs. For example, good energy conscious practices can result in reducing the load and thus reduce the size of the heating and cooling unit. Smaller heating and cooling units will cost less in the initial purchase price and use less energy. This synergistic effect could possibly help justify spending more on the energy efficient features.

There is no standard solution to an energy efficient building. The principles and technologies to use depend on the building orientation, geographic region, weather patterns, and humidity. Applying the principle or technology that is tailored to a building's specific environment will improve the energy efficiency of the building.

Although energy efficient practices are best implemented during the design phase, many strategies discussed in this report can still be utilized as an added feature or a retrofit to an existing building. The following are some of the techniques that can be implemented to achieve greater energy efficiency. The "whole building" is broken down into its individual components and discussed individually.

1.1 Building Envelope

The building envelope is the component that separates the interior from the exterior of the building. It includes the foundation, walls, windows, doors, roof, insulation, and seals. Deficiencies in any one of these can reduce the overall effectiveness of the building envelope as a whole. Designing and constructing a well insulated and airtight building envelope is the cornerstone to an energy efficient building.

1.1.1 Foundation

One aspect to pay attention to when designing or constructing a building is to eliminate thermal bridges, which allow heat to bypass the insulation. For example, buildings with slab floors provide a thermal bridge between the air surround the edge of the slab and the conditioned space inside. Careful design and construction can either eliminate the thermal bridges or neutralize them by specifying insulation where needed.

1.1.2 Walls

A light colored exterior reduces unwanted heat gain and also increases the lifespan of the product particularly on the south, west, and east facing walls.

Many manufacturers are developing new wall materials that are well insulated and easy to install. One such product is a prefabricated foam core wall shown in figures 1.1 and 1.2.

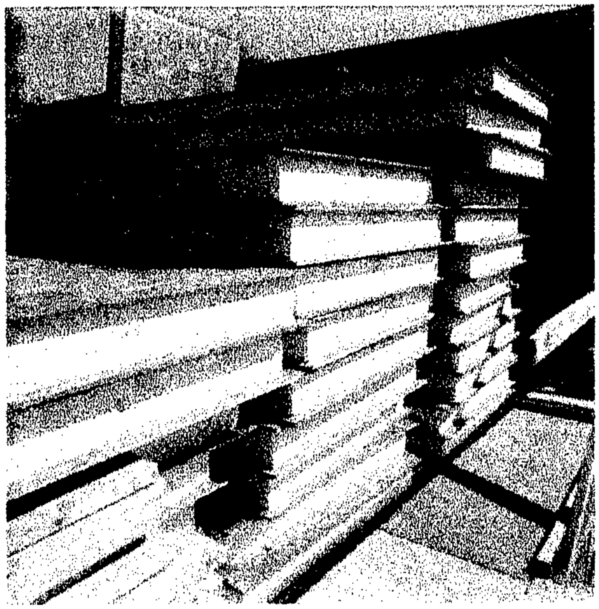


Figure 1.1 Foam core walls.

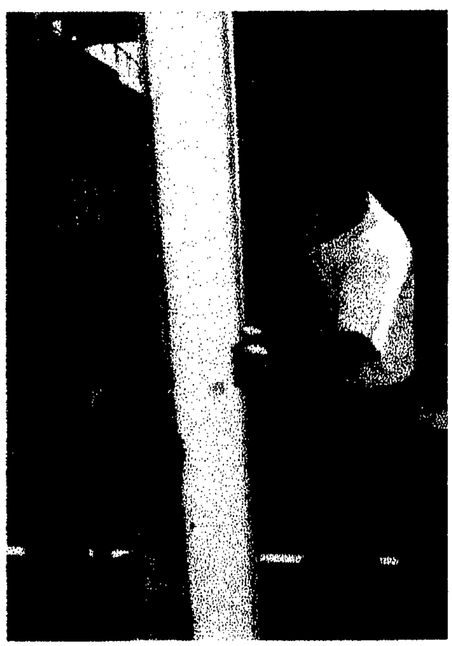


Figure 1.2 Foam core wall

1.1.3 Windows

About 40% of unwanted heat build up come through the windows. In existing buildings, window replacement is frequently a cost effective way to increase energy savings and comfort in the building.

Another alternative is to install reflective films on windows to reduce passive solar gain. The coatings are made of plastic sheets treated with dyes or a thin layer of metal. They are applied to the interior surface of the window. Besides keeping the building cooler, reflective films also cut glare and reduce fading of interior materials.

There are two main types of reflective coatings available. The sun-control films are best in warmer climates because they can reflect up to 80% of the sunlight. One disadvantage of this film, however, is that it reduces daylighting into the building. The other type of reflective coating is the combination film that allows some heat in and also prevents interior heat from escaping. The combination film is best suited for climates with both hot and cold seasons. If solar gain is desired in the winter, do not apply the films on the south facing windows.[4]

Window sizing and glazing (the glass and coatings) should be integrated into the building design since it affects daylighting, passive solar heating, and natural ventilation. The window's U-value is the critical factor in selecting an energy efficient window. The U-value is a measure of the window's insulating ability. Windows with lower values are better. The U-value of the window as a whole should be used because efficient glazing by poor frames. For example, aluminum frames are good heat conductors and should not be used.

The desired daylighting, passive solar heating, and natural ventilation determine the size and location of the window. In cold climates, large windows facing south allow significant passive solar heating inside and provide copious amounts of daylighting. During the summer, properly sized overhangs still allow daylighting and reduce the amount of passive solar heating as shown in figure 1.3. In warm climates, large windows facing north provide daylighting without heating the house. East and West facing windows should be small to minimize heat gain during the summer and heat loss during the winter. Minimize the window area on the east and west sides to reduce cooling load.

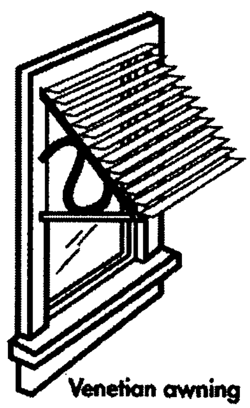


Figure 1.3 Overhangs provide shading and still allow daylighting

In climates where natural ventilation is desired, locate the windows on the windward and leeward sides of the building. The windows should be roughly equivalent in sizes on either side of the building to maximize the airflow. Offset the windows so that the air will circulate through the building rather than blowing through it.

Window shade and covering can also help in energy conservation. Window coverings provide shade for the window and reflect sunlight thus reducing the amount of passive solar gain. Window coverings are available that slide on tracks and provide a seal when closed to prevent air infiltration as shown in figure 1.4. The best use of window coverings to save energy and to increase comfort in the building is by closing them on hot summer days and cold winter nights and opening them on cool summer nights and during winter days. . Interior blinds are less effective but helps if they are reflective.

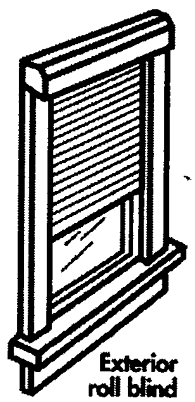


Figure 1.4 Window covering

1.1.4 Doors

Doors constructed of insulated metal or fiberglass is the best choice. However, since many commercial buildings use glass doors, the choice of glazing, size, and location of the door will depend on the desired solar heating or shading much like for windows as discussed above.

For heavily trafficked areas, air infiltration is a major consideration. Consider installing revolving doors or double-door entry to minimize to resolve the problem.

In homes storm doors are also effective at reducing heat loss and infiltration. Also sliding glass doors are popular in homes and the material selection should be carried out carefully much like for windows to achieve the desired energy saving strategy. Metal framed doors should have a thermal break to keep the heat from being transmitted through the frame.

1.1.5 Roof

Standard roofing materials add about a third of the unwanted heat build up in the building.[5] Although choosing a light colored roofing material will reduce heat gain from solar radiation by 30%, a better solution is to apply a reflective coating to the roof. Two such coatings are discussed in Chapter 2. Another solution to reflect heat is to install a radiant barrier on the underside of the roof. A radiant barrier is made of aluminum foil with paper backing and can reduce the heat gain by 25%. Single layer radiant barriers with kraft-paper backing cost about $0.13 per square foot ($1.44 per square meter) and the vented multi-layer product with fiber reinforced backing costs $0.30 per square foot ($3.33 per square meter). The multi-layer product also serves as insulation.

One method to remove unwanted heat from the attic is to install continuous soffit ridge vents to ventilate the heat in the attic. The addition of fans to ventilate the heat in the attic is also recommended.

1.1.6 Insulation

Where possible, incorporate high levels of insulation. Insulation is rated in terms of its R-value. Materials with higher R-value are better insulators and thus save in cooling and heating costs. Typically, higher R-value insulation is used on ceilings than on walls and floors. Refer to the Appendix for the U.S. Department of Energy

Recommended R-Values based on the geographic location in the United States. A more detailed discussion of the various forms of insulation material is discussed in Section 2.6.

The quality of insulation installation is also very important. A California study has shown that a 4% void in fiberglass batts reduces its effectiveness by 50%.[6]

1.1.7 Moisture and Air Leakage Control

Moisture control is an important element of the building envelope. If humid air comes in contact with a cold surface, condensation occurs and the water will cause damage. If the insulation gets wet, the R-value is reduced. One way to control moisture is to avoid thermal bridges such as from metal studs that provide a cool spot for moisture to form. Another method is seal off areas where air infiltration might occur such as around electrical outlets, switch plates, plumbing, wiring, and heating and cooling penetrations.

Vapor barriers or vapor retarders also can be used for moisture control. Forms of vapor barriers include polyethylene sheets, low permeability rated paints, laminated asphalt-covered building paper, vinyl wall coverings, and foil-type wallpapers. Batts or blanket insulation has the vapor barrier feature built into the material. Vapor barriers are installed on the "warm-in-winter" side of the insulation.

Air infiltrates in and out of a building through every hole, nook, and cranny. About one third of this air infiltrates through openings in the ceilings, walls, and floors of a typical residential building as illustrated in figure 1.5.

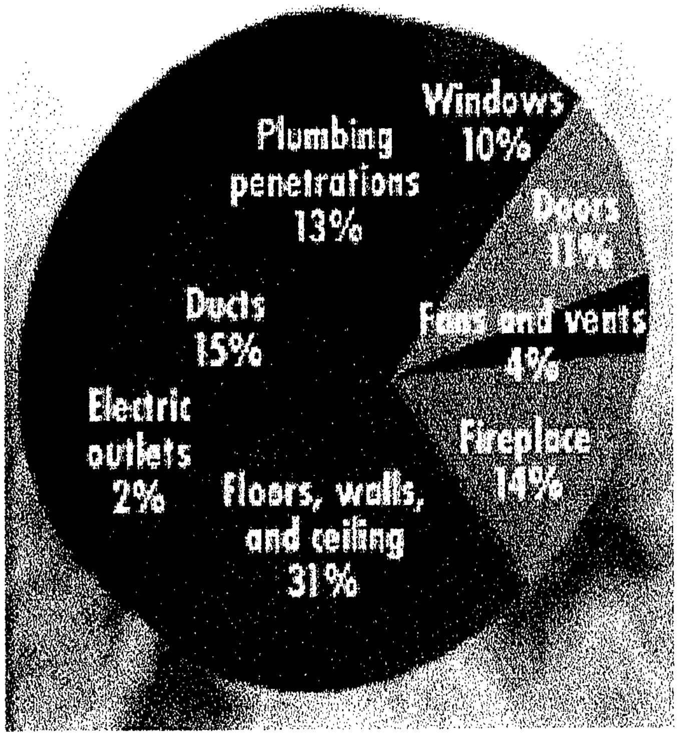


Figure 1.5

Air leakage control can be accomplished through the use of air infiltration barriers or air retarders. Air infiltration barriers are composed of an air impermeable component that is sealed off at all joints and penetrations to make the building airtight. If air infiltration barriers are located on the "warm-in-winter" side of the insulation, it can also act as a vapor barrier.

A major part of air leakage control involves sealing all joints such as at windows and doors with caulk or weatherstripping. Caulking around the frame and weatherstripping around the opening are inexpensive and easy method to conserve energy. When making a building airtight, however, adequate ventilation must be provided to ensure good indoor air quality and air circulation within the building.

1.2 Heating, Cooling, and Ventilation

Heating and cooling energy usage account for about 29% of the building's total energy usage in commercial buildings and a whopping 44% in residential buildings in the United States. See figures 1.6 and 1.7.[7] Well-insulated, reduced load and airtight buildings should minimize the size of the system required and may even eliminate the need for a central heating system. Integrating daylighting, passive solar heating, insulation, energy efficient windows, insulated doors, and landscaping into the whole-building concept will reduce the heating and cooling to a minor role.

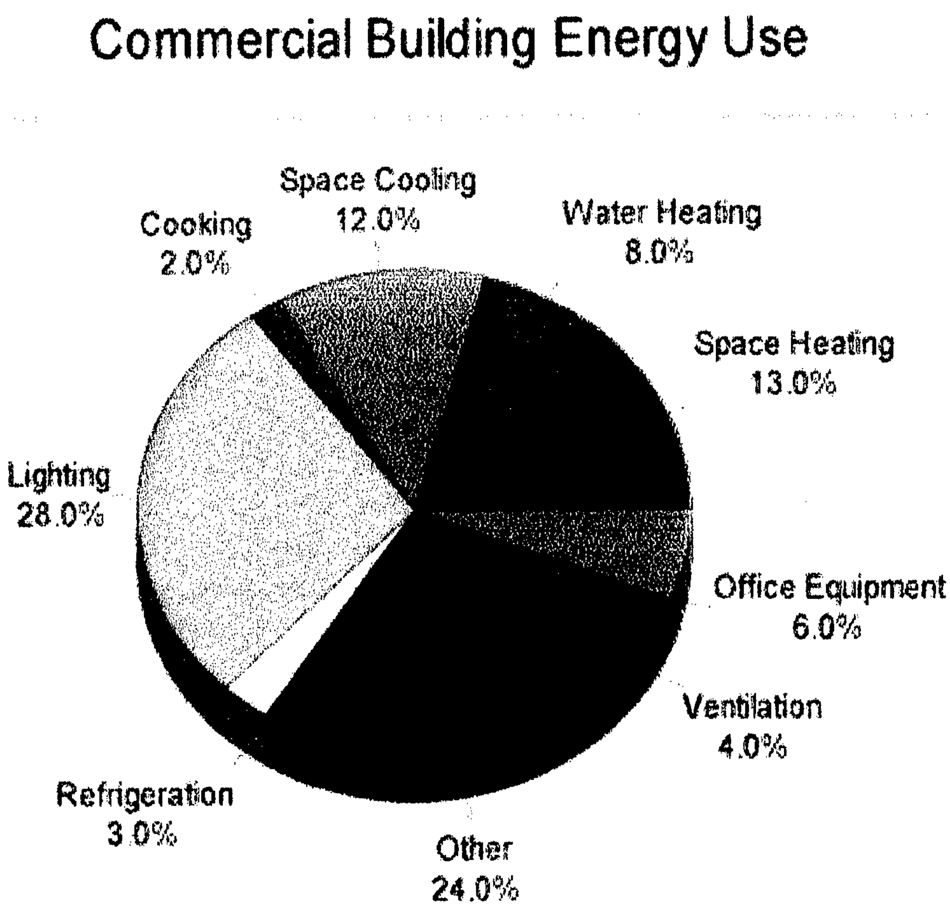


Figure 1.6

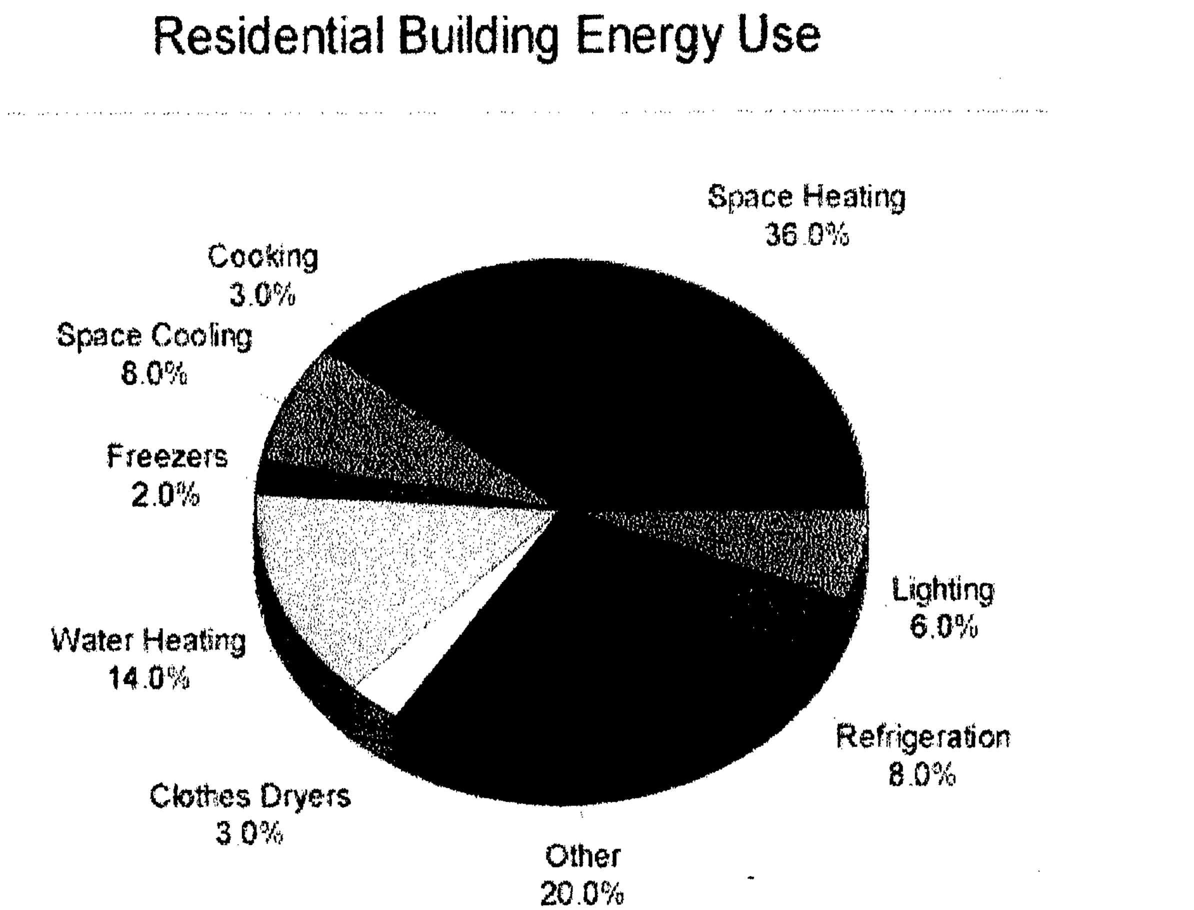


Figure 1.7

Existing homes can also benefit by upgrading the building with more insulation, sealing air leaks, and covering or retrofitting the windows. If the heating and cooling system is old and inefficient, it may be more advantageous to replace the unit with an energy efficient unit correctly sized to account for the other energy efficient upgrades.

Also, humidity sources from places like the basements and bathrooms hinder the evaporation or cooling effect on the skin of the body making the space feel hotter and uncomfortable. One energy efficient solution is to isolate the humidity to a room and install spot fans to ventilate the humid air to the exterior if possible.

1.2.1 Controls

Controls such as set back thermostats can save energy. For example, the thermostat can automatically adjust the settings during the night or when the building is not occupied to conserve energy. Yet comfort is maintained because the thermostat automatically returns the temperature to a comfortable when the building is occupied and active.

Some controls are even more sophisticated that can reduce the heating or cooling in the unused portion of the building while maintaining a comfortable temperature in the occupied rooms. "Smart" thermostats can help reduce energy usage by 6-33%.[8] A smart thermostat should allow program setbacks and have gradual temperature recovery.

1.2.2 Cooling

The most effective way to cool a building is through passive cooling which uses non-mechanical methods to maintain a comfortable environment in the building. Passive approach to cooling involves keeping the heat from building up in the first place. Sources of heat build up include heat absorbed through the building envelope, air leakage, and the heat generated within the building by lights, appliances, and equipment. Thus the passive approach to preventing heat gain include using light colored or reflective material on the exterior of the building to reflect sunlight and reducing or eliminating heat generating sources in the building. Dark or dull exterior colors can absorb 70% to 90% of the sun's radiant energy hitting the material.[9] On the other hand, light colors can reflect most of the heat away.

Most commercial buildings use chillers for air conditioning. However, this technology is in transition due to the phasing out of the standard chlorofluorocarbon (CFC) refrigerants to other refrigerants. Some manufacturers have seized this opportunity to develop new cooling technologies that could improve efficiency, cost-effectiveness, comfort, indoor air quality, and humidity control rather than redesigning the chillers to use other refrigerants. Two such new technologies are cool storage and desiccant evaporative cooling which is discussed in Chapter 2.

A central air conditioner is generally more efficient than a room air conditioner. However, if only a small portion of the building requires cooling, a room unit may be more efficient. Select a central air conditioner with a high seasonal energy efficiency ratio (SEER) and a room air conditioner with a high energy efficiency ratio (EER).

1.2.3 Heating

Although older forced air and hot water boiler systems are only about 60-70% efficient, modern heating systems can achieve up to 97% efficiency.[10] To achieve high efficiency, it is critical that the system is properly sized. The most efficient size is a system that can run constantly at full load on the coldest day that the building is designed to handle. Therefore, it is best to first improve the energy efficiency of the building before resizing and installing a new high efficiency furnace. Although designers generally oversize a system to provide a margin for error, an oversized system will not run efficiently at partial loads. It will also cycle on and off more frequently putting more wear on the system.

Groups of buildings such as on college campuses can save energy by implementing a heating district, which uses a central heating system to pump hot water for heating to a number of buildings. The advantage of such a system is that it achieves an economy of scale and reduces the operation and maintenance for the individual buildings.

In areas where geothermal energy such as hot springs exists, the heating district concept is ideal to take advantage of the free hot water to heat the buildings. A diagram of a geothermal system is shown in figure 1.8.

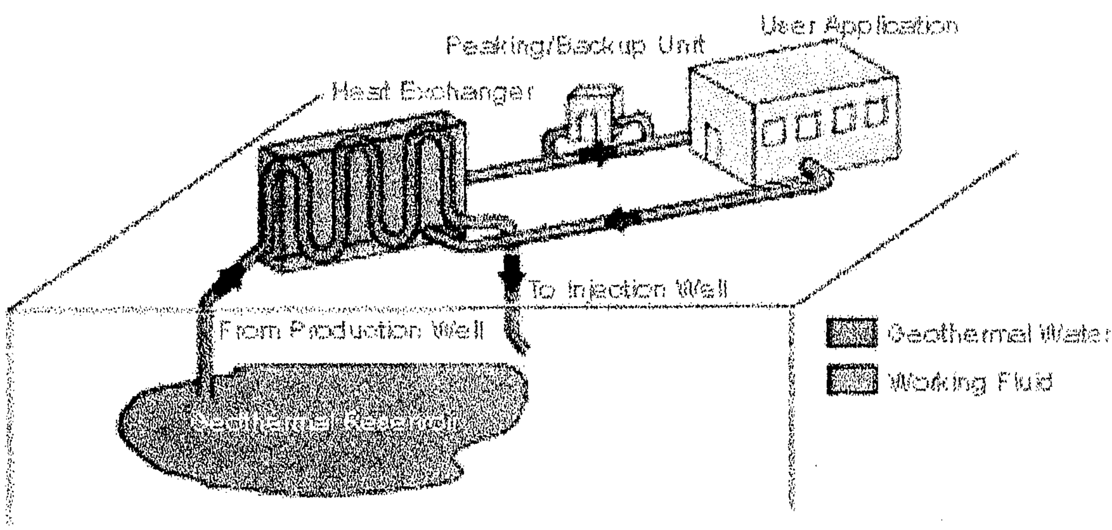


Figure 1.8 Geothermal System

Electric baseboards may be installed in lieu of a central heating system for superinsulated buildings with very small heating loads. Electric baseboards are less efficient than a central heating system but it is much less expensive.

For larger heating loads, install the highly efficient heat pumps. In moderate climates, air-source heat pumps work well and also provide air conditioning in the summer. In cold climates, a ground-source heat pump should be used, as the ground is a much better source of heat than the air during the cold winter months.[11] Heat pumps are discussed in more detail in Chapter 2.

1.2.4 Ducts

Ensure the mechanical system and ductwork is matched to the size of the load. Ductwork should be minimized by running it to the closest point in each room to save on length of run and leakage. To reduce leakage, insulate the ductwork and ensure joints and seams are sealed with mastic, not duct tape. The ductwork should be installed through conditioned areas when feasible to reduce lost of conditioned air through unconditioned areas.

1.3 Building Orientation and Landscaping

Building orientation and the surrounding landscaping work together to reduce energy consumption. A well designed and oriented building uses the sun to reduce winter heating bills, provides shading to reduce summer cooling bills, and minimizes the winter wind chill.

In general, buildings in the U.S. should have the long side face south to allow the low winter sun to warm the side of the building with the largest surface area. Figure 1.9 shows a building with many south facing windows to take advantage of passive solar heating. During the summer when the sun is low during early morning and the late afternoons, the building would stay cooler by allowing less heat in on the west and east sides which has less surface area.

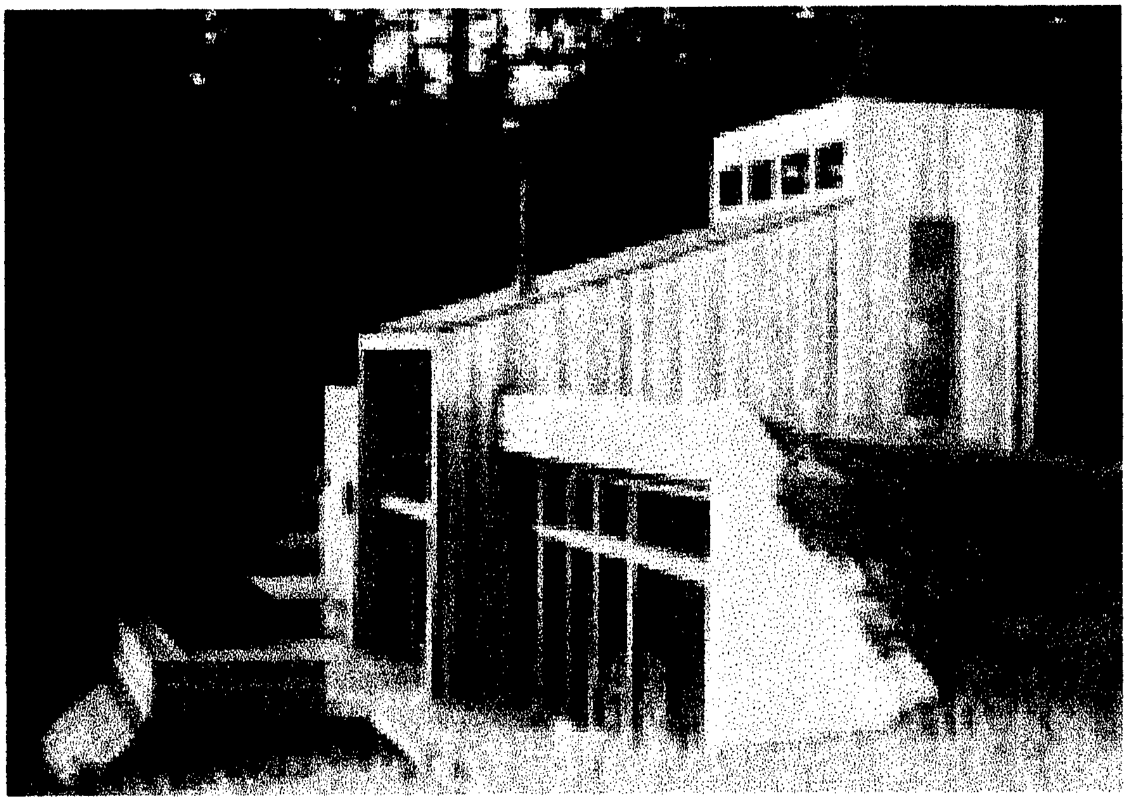


Figure 1.9

Shading of buildings can reduce indoor temperature significantly and be accomplished with landscaping, trees, and shrubs. It is best to provide shading to east and west facing windows and to the roof of the building. Deciduous trees are best for shading as they shed their leaves in the winter to provide more sunlight and solar gain for the building. Vegetation around the exterior of the building also keeps the building cool through evapotranspiration. During photosynthesis, the vegetation gives off large amounts of water vapor, which absorbs the heat to cool the area. Also, the generally dark vegetation absorbs the solar radiation rather than reflect it onto the building.

Trees, fences, walls, and other nearly buildings should be used to block or channel the winter winds away from the building. Winter winds can be deflected by planting trees and shrubs on the north and west sides of the building. Summer winds can be deflected by planting on the south and west sides of the building. A well-landscaped building not only provides shading but also offer protection from winds and a beautiful vista.

1.4 Solar Energy

Consider utilizing renewable energy resources such as photovotaics. This technology will be discussed more extensively in Chapter Two.

Another way to take advantage of solar energy is through water heaters. Solar water heaters are cost competitive in many applications when the life cycle cost is considered. Although the initial installation and equipment costs are higher than conventional water heaters, the fuel (sunshine) is free. The payback period is from 4 to 8 years on a well designed solar water heating system.[12] In addition, it is environmentally friendly. To encourage the use of solar technology, some local or state governments even offer tax incentives.

1.5 Lighting

Lighting consumes large amounts of energy particularly in commercial buildings. Combining daylighting and energy efficient electric lighting will result in the best lighting with the least energy usage. Using less electric lighting will result in a lower cooling load because less heat is dissipated from the lights. By accounting for this, a smaller air conditioning unit will be required to increase the savings in equipment and operating costs.

Lighting accounts for 28% of the energy use in commercial buildings and only 6% in homes. Installing energy efficient lights, fixtures, and controls can reduce energy usage. Recent innovations in lighting such as electronic ballasts, dimmable fluorescents, and other technologies have revolutionized the industry. Retrofitting lights with the new energy efficient bulbs are often cost effective with the pay back period of only a few years. When install new lights, specify energy efficient airtight lighting. Airtight lighting prevents transfer of conditioned air to the attic.

The most economical lighting yet is daylighting. Daylighting is the use of direct, diffuse, or reflected sunlight to provide full or supplemental lighting for building interiors. Using daylighting not only saves on the electricity for artificial lighting, but it can also reduce heating and cooling costs. Since daylighting produces less heat per unit of illumination than many artificial lights, it may reduce cooling costs. As part of a passive solar heating system, sunlight can provide supplementary building heat. Figure 1.10 shows a building that takes advantage of daylighting.

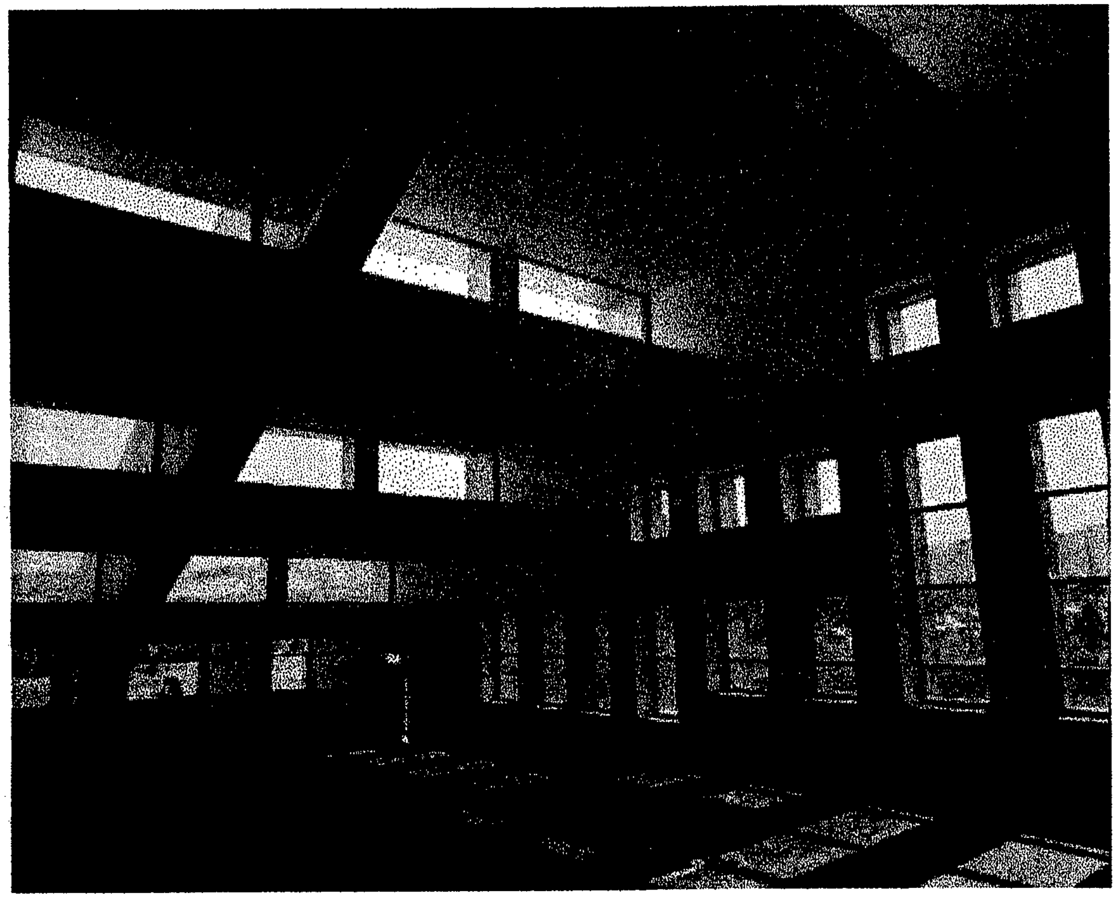
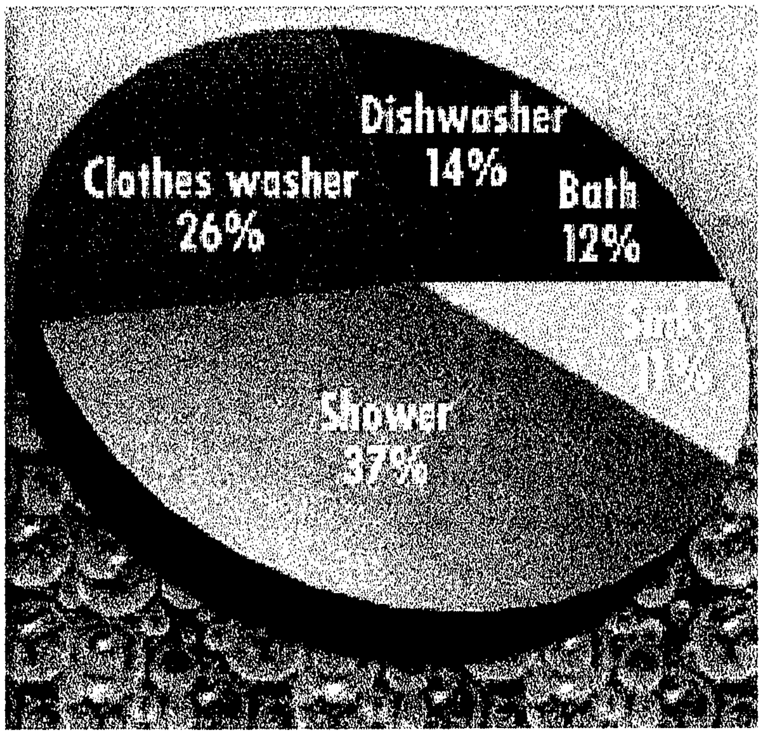


Figure 1.10

1.6 Water Use

Water heating comprises 8% of the total energy use in commercial buildings and 14% in homes. Solar water heating is an energy efficient option in reducing energy use but there are also other non-solar options for energy conservation. In commercial buildings, water heating is best accomplished using integrated space heating and water heating systems.

In residential buildings, hot water heaters are another source of energy savings. Figure 1.11 shows where hot water is used in a typical home. In warm climates, locate the hot water heater in an unconditioned part of the house such as the garage so that it does not transfer heat into the house. Otherwise, locate close to the kitchen and bathrooms to minimize losses through the pipes. Another important energy saving tool is insulating the hot water pipes and heater.



Hot Water Usage

(based on national averages)

The typical U.S. homeowner's water consumption by place of use.

Figure 1.11

The trend in plumbing is toward low-flow fixtures. The 1992 Energy Policy Act limited the flows of most fixtures. Not only do they conserve water, they conserve energy by reducing the amount of hot water used and wasted. Studies have shown that homes retrofitted with low flow fixtures can save $30-50 annually on water heating.[13]

There are a wide variety of plumbing fixtures and appliances available that minimizes hot water use. In bathrooms, faucet aerators and low-flow showerheads reduce the amount of water used. Low-water use appliances such as dishwashers and horizontal-axis washing machines can provide significant energy savings.

Reducing water usage will also save the energy used to purify the water and to treat the wastewater.

1.7 Office Equipment and Appliances

Office equipment consumes 8% of the total electric energy used in commercial buildings. It will pay handsome dividends to install energy efficient office equipment. Not only does energy efficient equipment reduce energy consumption but it also generates less heat inside the building thereby decreasing the size of the air conditioning unit.

Office equipment typically sits idle for most of the day. Since this totals an enormous amount of wasted energy for the country as a whole, the Department of Energy and the Environmental Protection Agency have teamed up to promote the Energy Star label program. This program allows the manufacturer to add the Energy Star label to any equipment that meets the energy-efficiency specifications set by the EPA. The Energy Star label program is discussed in more detail in Chapter 5.

Appliance consumes a hefty 20% of the total electric energy used in residential buildings. Refrigerators, freezers, clothes washers, dryers, dishwashers, and ranges are the primary energy users in a home. With the help of federal mandates, some appliances on the market today are now much more energy efficient. In the past decade, the standard top-loading washers have become twice as efficient. Refrigerators in the 16-20 cubic feet size tend to be more efficient. Also, units with the freezer on top are more efficient than the side-by-side configuration. The microwave oven cooks much faster, generates less heat, and uses much less energy than conventional ovens. Depending on how much hot water in used in hand-washing dishes, dishwashers can save more energy and water.

All major appliances sold in the U.S. come with an ENERGYGUIDE label that indicate their efficiency. Consumers should compare these labels prior to purchase and evaluate the life cycle cost of the appliance. A more expensive appliance with better features and more energy efficient may very well have a lower life cycle cost than a less expensive and inefficient older model.

Many of the strategies listed above are intended to keep the warm air inside during the winter months and keeping the warm air outside during the summer months. Figures 1.1 and 1.2 shows gives a breakdown of how energy is used in a commercial and residential building. Knowing what is the largest energy load in a facility will help in targeting areas where to invest for the greatest return. Although implementing these techniques will likely result in higher initial cost, the HVAC equipment and distribution system can be downsized. The lower initial HVAC cost along with the lower life cycle cost could help justify the added initial expense.

CHAPTER TWO
ENERGY EFFICIENT PRODUCTS

There are many energy efficient products on the market today. The following is a description of some of the technologies that are available. It is not intended to be an all-inclusive list but rather to present a broad range of products used in the building industry. The names of products and manufacturers presented below are intended to provide specific examples. There may be other competitors that provide the same or similar products.

2.1 Foundation

Conventional foundations are made of concrete and formed with plywood. When the concrete hardens, the forms are removed. There is very little insulation value in this system. An energy efficient alternative for foundations is a stay-in-place concrete form made of expanded polystyrene (EPS) foam that also acts as an insulator. The product can be used above or below grade in both residential and commercial applications and can achieve a R-22 thermal resistance. Other advantages of the product are greater strength, moisture resistance, air tight, sound suppression, faster to install, easily fastened by interior and exterior finishes, and uses less concrete. It costs about 20% more than the conventional system however. A national distributor for this product will guarantee the product to save 70% on heating and cooling costs.[14]

2.2 Structural

A common practice in commercial construction is to build walls using hollow masonry blocks and then fill with concrete. However, it has very little insulation value.

An alternative that provides up to R-13 of insulation value is to substitute the masonry blocks with ones made of waste or recycled wood chips bonded by cement and molded into hollow blocks.

2.3 Sheating/Exterior Finish

Sheathing is used to provide a backing for fastening the exterior finishes and also serves as a secondary weather barrier. Typically it is made of plywood or oriented strand board. An energy efficient alternative is to use the Thermo-ply sheathing made by Simplex Products Division. It is made of recycled cardboard and mill waste. It is strong and can add up to a 3.5 R-value to the building.[15]

2.4 Roofing

About a third of the unwanted heat comes into the building through the roof. This is hard to control using standard roofing materials. For example, even light colored asphalt shingles absorb about 70% of the radiant heat.[16] One good solution is to apply a reflective coating to the roof. There are two such coatings available commercially. One coating is a white latex that can be applied over asphalt and fiberglass shingles, tar paper, and metal. This product usually comes with a 5 year warranty. A second coating is asphalt based that contains glass fibers and aluminum particles. It can be applied to most metal and asphalt roofs. However, this coating has a tacky finish that attracts dirt, which reduces the reflectivity.

A new energy efficient roofing material is a recycled aluminum shingle that reflects 92% of the radiant heat and can reduce attic heat by up to 34%. It has a shake shingle appearance and comes with a 50-year non-prorated warranty whereas typical residential roofing is made of shingles with a 15-20 year life span. It has a wind rating of 110 mph and is hail resistant.[17] Figure 2.1 shows the shake alumium shingle on a home.

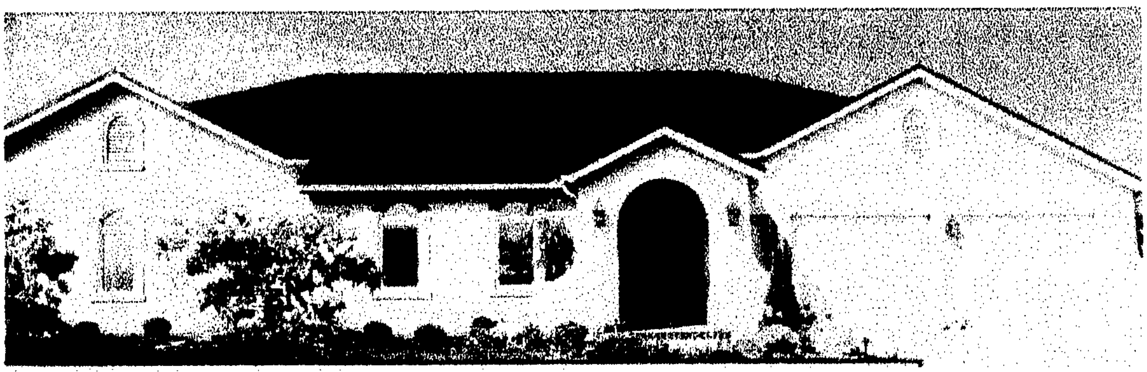


Figure 2.1

2.5 Windows

In residential houses, windows account for 15-30% of the heating load and over 50% of the cooling load.[18] Over the past 15 years, new technology has increased the performance of windows by 50%. Low-emissivity (low-e) glass coatings have effectively increased the R-value from 2 to 3.

Low-e coatings were first introduced in 1979. The coating essentially reduces the heat emitted from the warm pane to the cool pane, which in essence makes the glazing an insulator. It is a thin coating of silver or tin applied on the glass surface. In cold climates, the coating is applied to the interior of the outside pane to keep the warm air inside. In warm climates, the coating is applied to the exterior of the inside pane to keep the warm air outside. Low-e coatings are not desired if passive solar heating is preferred. The coating reduces the glazing's ability to transmit solar heat.

Low-e coatings cost 10-15% more but the pay back period is only a few years. Double low-e coatings are also available that can increase the R-value to 8. Inert gases such as argon or krypton fill the space between the glazing layers because they do not conduct heat. By balancing the heat loss, solar gain, and light transmission properties, window selection can be optimized. For example, solar gain may be preferable on the south facing windows in cold climates so low-e properties may not be desirable.

Reflective/tinted glass coatings may also be used to cut down on the solar heat gain but they transmit less light. Super high-performance windows can be manufactured combining multiple glazing, multiple low-e coatings, and low conductivity inert gases. One manufacturer has demonstrated a prototype of a window that has a R-20 insulating value.[19]

Window frames constructed out of wood or foam filled fiberglass should be preferable over aluminum and vinyl frames. Aluminum conducts too much heat and vinyl has problems providing a good seal when contraction and expansion occurs. A good idea is to select windows with multiple weather-stripping to keep the building airtight.

2.6 Insulation

Insulation is perhaps the most import element of energy conservation. The industry standard is fiberglass insulation. High-density fiberglass insulation could be applied to the same cavity for a 15-20% gain in performance. The more expensive rigid foam insulation can achieve even higher R-values. However, except for the expanded polystyrene (EPS), rigid foam insulation emit HCFC's, a greenhouse gas, into the environment. EPS is considered a lower grade of rigid foam insulation because of a lower R-value. An alternative is to use the rigid fiberglass board, which does not generate HCFC's.[20] Rigid insulation is a better insulator than cavity filled insulation because it covers the framing members thereby reducing thermal bridging.

Another type of insulation that is environmentally friendly is made of high-quality engineered paper and wood fibers. It can be applied into open cavities by a damp spray method or loose in the attic. It is a better insulator than fiberglass and rated at R-3.7 per inch. It minimizes convection flow as it fills in most voids and forms a monolithic blanket that attaches to the insulated surface.

2.7 Mechanical Systems/HVAC

2.7.1 Heat Pumps

The most energy efficient heating and cooling system is the heat pump, which can generate more than 10 times the amount of energy it consumes.[21] It can be the air-to-air or ground source type. Pictures of the air-to-air and ground source heat pumps are shown in figures 2.2 and 2.3. In the heating cycle, the unit removes heat from the outside and pumps it indoors. In the cooling cycle, it reverses and removes heat from the inside and pumps it outside. Ground source heat pumps reduce energy usage by as much as 44% compared to air-to-air heat pumps and 72% compared to conventional resistive heaters and air conditioners.[22] Ground source heat pumps are more efficient to operate because they take advantage of the relatively constant ground temperatures. Although ground source heat pumps cost less to operate, they also cost more to install. For a ground source heat pump, a series of pipes is buried either horizontally or vertically in the ground near the building. A fluid, usually water with antifreeze, is circulated through the pipes to absorb or discharge the heat depending on whether the heating or cooling effect is desired. If the building is located near a body of water such as a lake or a pond, water-source heat pumps has similar advantages.

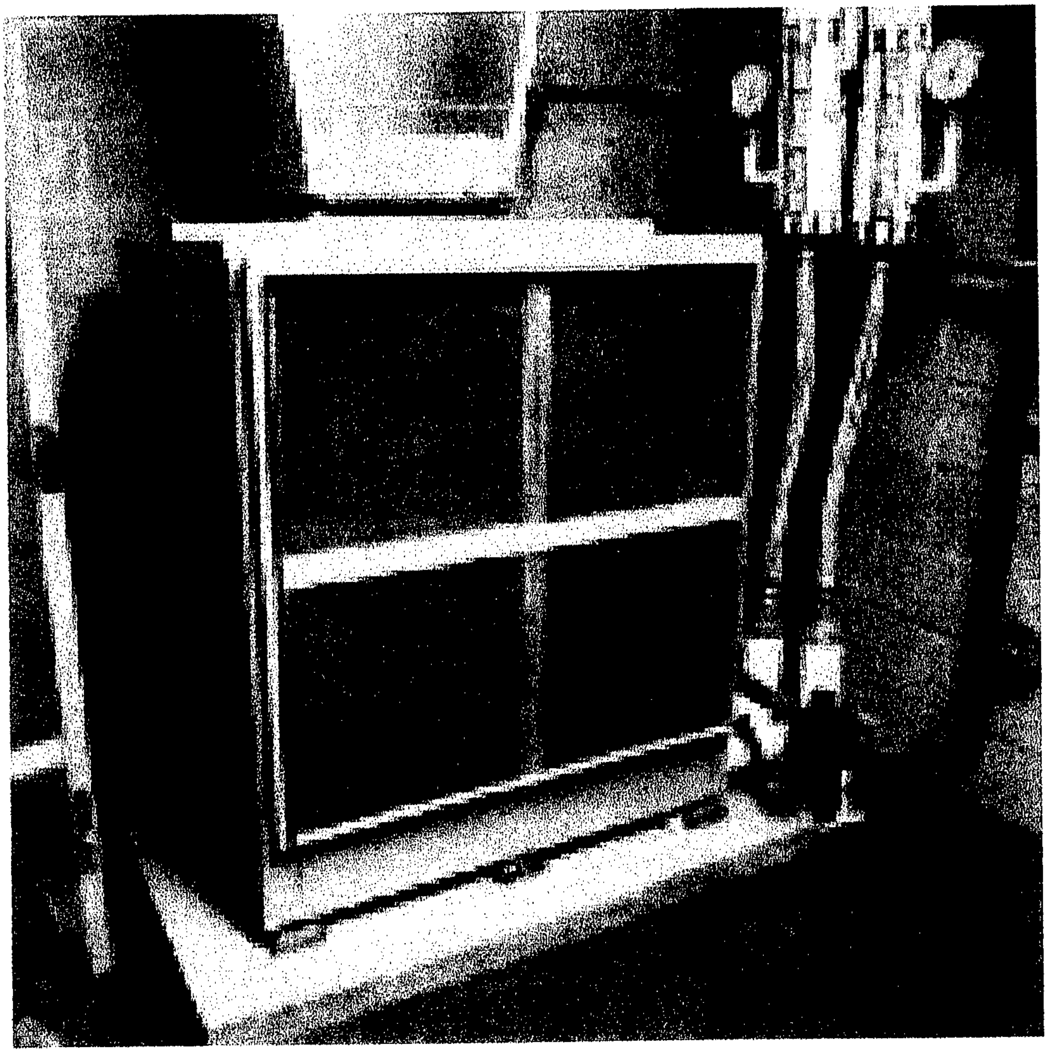


Figure 2.2 Air-to Air Heat pump

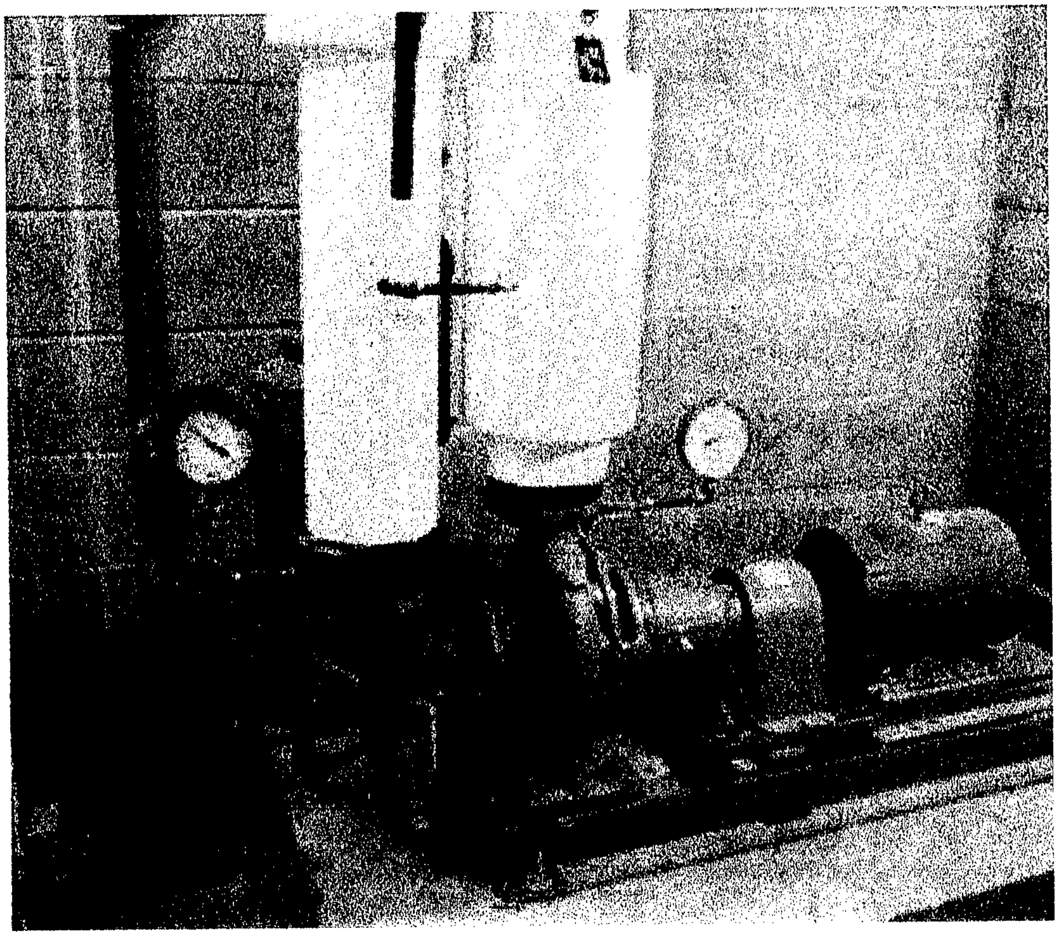


Figure 2.3 Ground Source Heat Pump

Ground source heat pumps can also provide virtually free hot water year round. Many systems are equipped with desuperheaters that transfer excess heat from the heat pump's compressor to the hot water tank. However, desuperheaters can only heat hot water when the heat pump is in operation. Since ground source heat pumps are so much more efficient than other means of water heating, manufacturers are beginning to offer full demand system with a separate heat exchanger to meet the building's hot water needs.

2.7.2 Cool Storage

Cool storage involves using the chiller at night to make ice or some other material with low latent heat. The ice is then used during the day to add to the cooling. This concept allows the chiller to operate more efficiently at a steady load throughout the day and night. The chiller is less efficient when operating at the extremes of low load or high load. Operating at steady load also extends the capacity and operating life of the chiller.

2.7.3 Evaporative Cooling

Another approach to air conditioning is evaporative cooling, which relies on the latent heat of evaporation to cool the air. Evaporative cooling is energy efficient, environmentally safe, and economical. The warm air transfers energy to evaporate the water so that the air becomes cooler. A fan then circulates the cool air through ductwork into the building. Evaporative cooling is appropriate in dry and hot climates.

Evaporative cooling can be extended to humid climates with the addition of a dessicant, which dries the incoming air before it is passed through the evaporative process. However, the desiccant evaporative cooler is less efficient than the standard evaporative cooler because the desiccant must be regenerated (removing the moisture) by passing heat through it. Various technologies have been developed to regenerate the desiccant including the use of waste heat, natural gas, electricity and solar energy. The desiccants that are available commercially include silica gel, activated alumina, natural and synthetic zeolites, titanium silicate, lithium chloride, and synthetic polymers. Despite the energy penalty, desiccant evaporative coolers are still more efficient than chillers and can realize significant energy savings. Desiccant evaporative coolers can be used in most commercial buildings and is CFC free. Engineers and scientists are in the process of developing second generation desiccant systems for broad commercial and residential use. Since desiccant cooling also dehumidifies the air, it is estimated that desiccant cooling could reduce residential electricity demand by as much as 25% in humid regions.[23]

2.8 Lighting and Electrical

Lighting is a major energy load particularly in commercial buildings as they rarely take advantage of daylight. Lighting generates heat that increases the load on air conditioners. There are a number of types of lights available and they should be matched to the setting and the quality of light desired.

Fluorescent lamps are about four to five times more efficient than incandescent bulbs. The new electronically ballasted fluorescent turns on instantly and has eliminated the hum and flicker of the old magnetically ballasted technology. Compact fluorescent lights are now smaller and can generate light quality comparable to that of incandescent light.[24] Although compact fluorescent lights are more expensive, they last much longer and use much less energy than incandescent lights. To demonstrate the efficiency of these bulbs, compare a 60-watt, 775 lumens incandescent bulb to a 32-watt, 3,050 lumens compact fluorescent bulb. It produces about four times the light at half the energy use. Figure 2.4 shows some compact fluorescent bulbs available commercially.

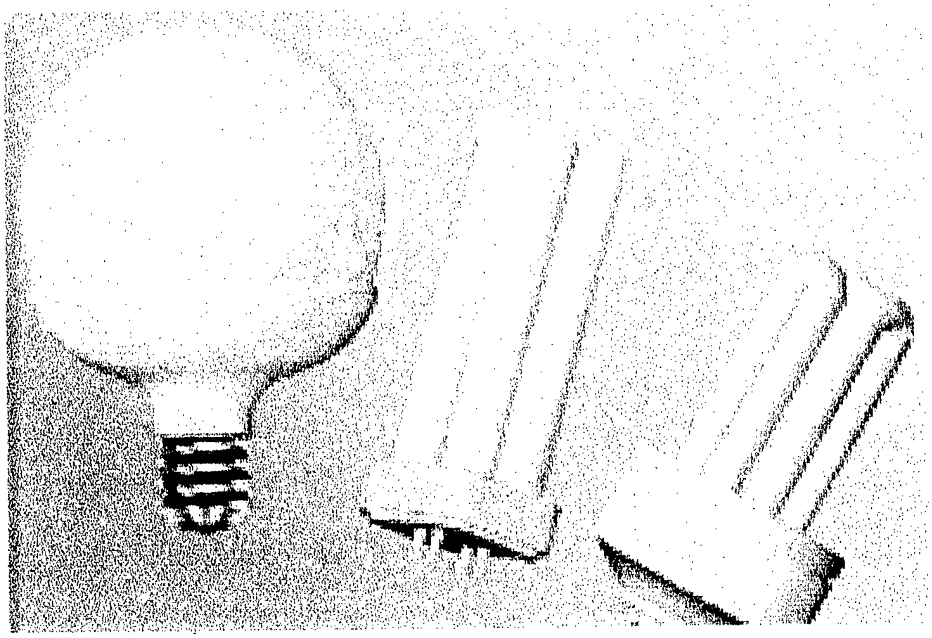


Figure 2.4 Compact Fluorescent Bulbs

There is also an option to use an improved deflector to further increase the efficiency of the fluorescent light. The deflector will allow the number of bulbs per fixture to be reduced while maintaining the same amount of light.

Other types of energy efficient lighting include metal halide, high and low pressure sodium, and sulfur types.

2.9 Appliances

A relatively new product that is not yet widely available in the U.S. is the horizontal-axis washing machine. It uses about 50% less water than the conventional top-loading washer.[25] It also spins much faster during the spin cycle thereby removing more water from the clothes. This reduces the amount of energy needed for drying. The horizontal-axis washing machines cost at least $200 more than a comparable vertical axis machine.

CHAPTER THREE
PHOTOVOLTAIC SYSTEMS

One energy efficient product that could have the move widespread use and garner the most energy savings is the photovoltaic (PV) technology. Buildings in the U.S., both residential and commercial, use about 29 quadrillion BTU's (quads) of energy each year and account for 35% of total energy consumption. On the other hand, over 2 billion people in the world have no electricity. Considering such a large electrical load in the U.S. and the mass of people without electricity, photovoltaic technology has came on the scene as a viable solution to two of the world's biggest problems. It can provide the world with clean renewable energy and increase the quality for life for masses of people.

3.1 History and Milestones

Photovoltaic is a relatively new technology and is still in its infancy. It was born in the United States in the early 1950's with the invention of the silicon solar cell at Bell Laboratories. Then the oil embargo and crisis of 1973 occurred which generated much interest in alternative forms of energy to fossil fuels and brought PV technology into the forefront. As a result, the United States embarked on a comprehensive research and development program to bring this technology into large-scale use. With investments from major industrial giants such as General Electric, Westinghouse, and Exxon, and leadership from the federal government, PV technology has come a long way in improved efficiency and reduced costs.

In 1980, Solar Design Associates, under contract from the Department of Energy and support from the Massachusetts Institute of Technology, built the first building-integrated PV system (BIPV systems will be explained in the next section) and the first residence ever to be powered by a utility-interactive PV system. It shares its surplus power with the utility grid. The energy efficient "Carlisle House" as it was called, shown in figure 3.1, was constructed in Carlisle, Massachusetts and featured passive solar heating and cooling, super insulation, a roof-integrated solar thermal system, and a 7.5 KW PV array of polycrystalline modules manufactured by Solarex.

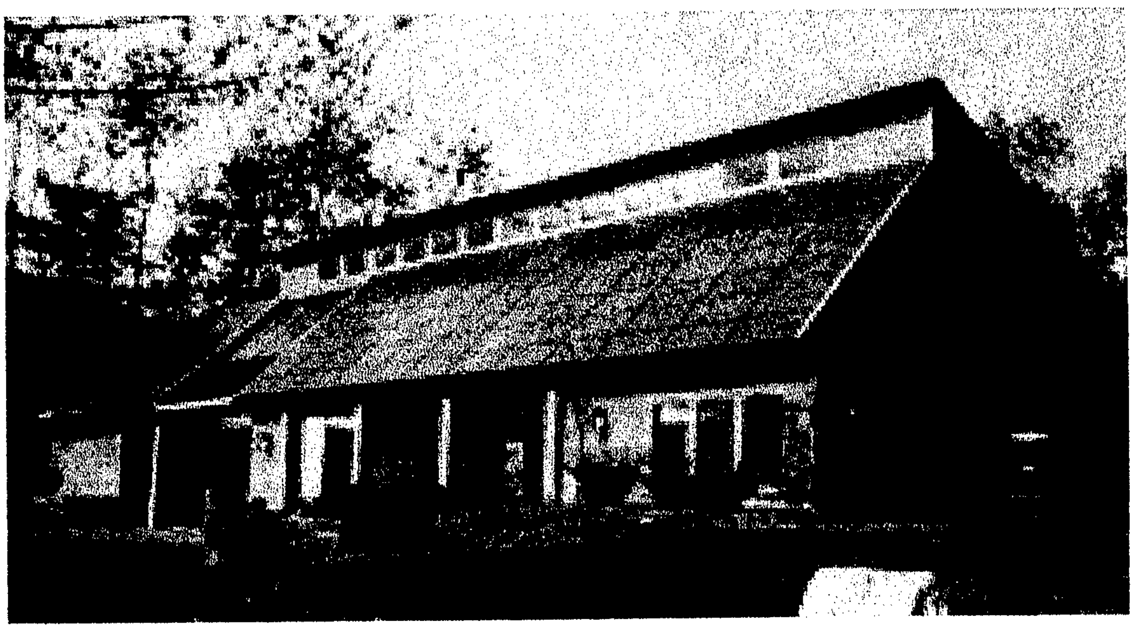


Figure 3.1 Carlisle House

In 1982, the Solarex Corporation of Frederick, Maryland showed its commitment to this technology by building a 200 KW PV array, shown in figure 3.2, to power their entire manufacturing plant. A large bank of storage batteries was also installed to provide an uninterruptible power source for critical plant systems.

Figure 3.2 Solarex 200 KW array

In 1985, the world's first PV powered neighborhood was born in Garner, Massachusetts. It fielded a 100 KW distributed grid-connected rooftop PV system sponsored by the New England Electric System. Following the pioneering work of Garner, many communities have started systems of their own. One notable example is the Sacramento Municipal Utility District (SMUD) in California, which fielded a neighborhood distributed rooftop PV system that reached 200 KW as of 1995 and growing. SMUD and the city provided incentives and subsidies that were such a success that it has generated a healthy backlog of requests for these systems by the city businesses and residents.

3.2 Current Trends

Current research and development is in the area of Building Integrated Photovoltaics (BIPV). BIPV modules are usually made an integral part of the building, often serving dual purpose as an exterior building material as well. Such dual-purpose construction helps to effectively reduce the cost of the PV system. BIPV applications are usually connected to a utility's grid and can generate enough power to cover the building's load over the course of a year. During daylight hours, the BIPV system can generate power in excess of building demand and reverses the power meter. Another advantage is that it effectively nullifies peak demand charges. During hours of darkness, the building draws power from the grid. This offset can balance out during the course of a year so that the net power consumption from the grid is negligible. Currently, there is much debate in the utility industry as to how to charge customers that have such systems and whether utility customers will have to pay customers who generate excess power. Each state and even each utility district has its own rules.

3.3 Building Integrated Photovoltaic Applications

BIPV systems can replace existing building components such as wall glazing, roof materials and windows. More specifically, among some of its uses are curtain-walls, skylights, atrium roofs, awnings, PV roof tiles, and semi-transparent PV windows. Commercial buildings such as office, retail, school, and hotel buildings offer good near-term possibilities for the use of BIPV. Figures 3.3 through 3.7 show some applications of BIPV systems. According to recent studies, at least 60 percent of commercial buildings in the U.S. are more than 30 years old. Many of these will need to be remodeled, repaired, or replaced soon. Systems offering the greatest economic potential, both in new construction and retrofits, are BIPV skylights, atrium roofs, and awnings. Prototype PV products are currently being developed and tested that could replace conventional windows, skylights and walls while generating electricity. As an added bonus, these components can be aesthetically and architecturally pleasing to enhance the organization's image.

Figure 3.3 PV Exterior Walls

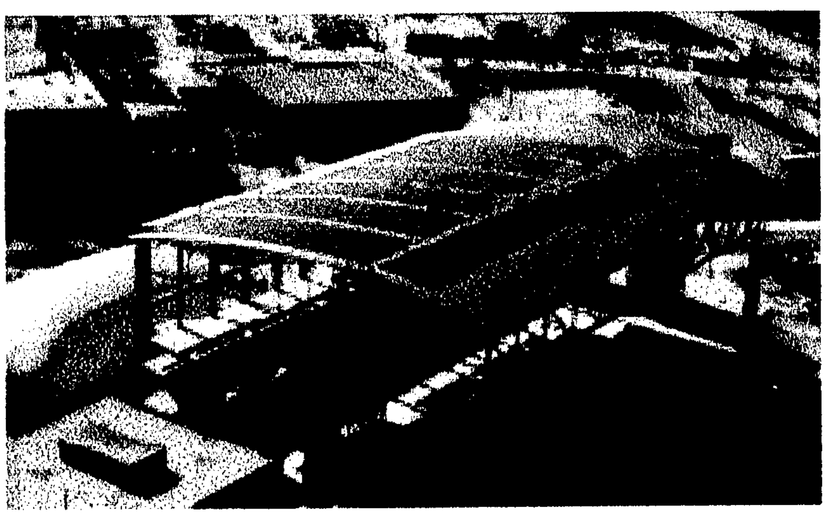


Figure 3.4 Swimming pool at Olympic village, Atlanta

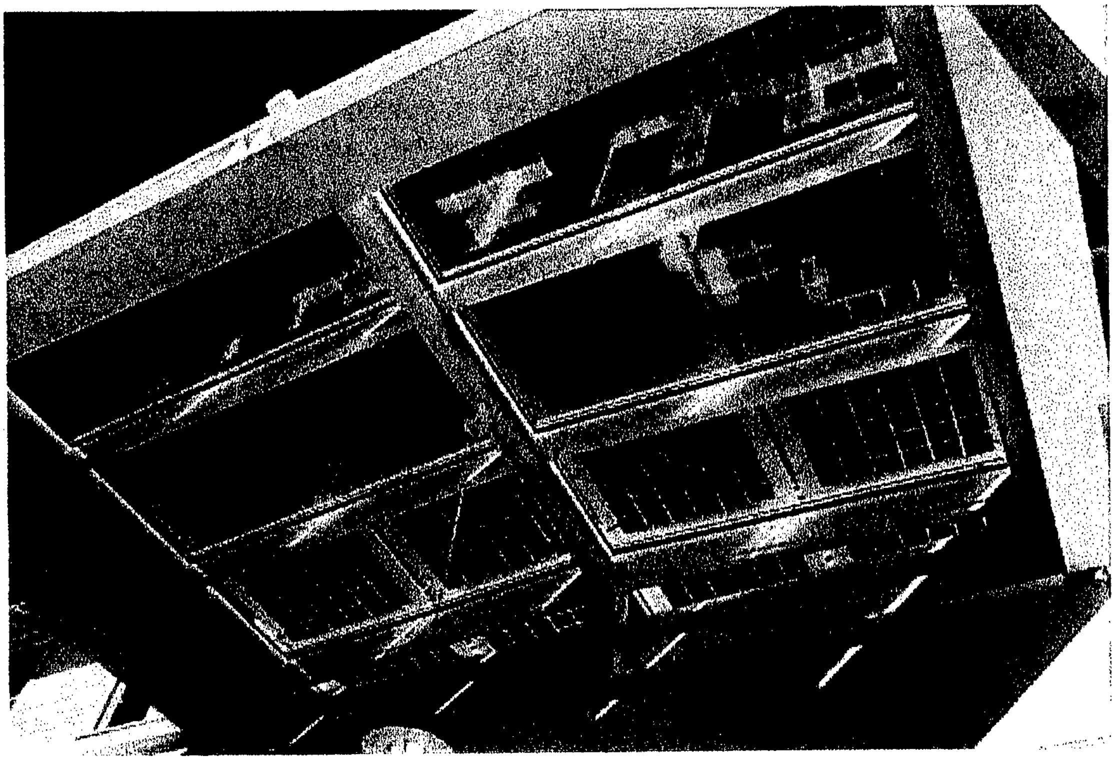


Figure 3.5 PV Awnings

Figure 3.6 Thermal and PV solar panels side by side

Figure 3.7 PV shingles being installed

3.4 Construction

PV systems can be a stand-alone system or tied to the grid. A stand-alone system is advantageous in remote locations where it is too costly to bring in grid power. Thus it is ideal for rural and undeveloped areas of the U.S. For example it may cost as much as $20,000 to bring in power from 500 yards away but a PV system may meet the location's power demand that does not cost as much. Stand-alone systems also holds much promise in much of the world where an estimated 2 billion people does not have electricity. In the U.S., grid connected systems are much more prevalent since electricity is ubiquitous. This has an advantage in that the expensive batteries and power electronics and back up generators are not required. The grid effectively serves as the storage medium. It should be noted that there are solar thermal collectors that are usually used in conjunction with the PV system. The thermal collectors are more effective at heating and water heating, whereas, the PV system provides the electricity to power the electrical appliances, lights and equipment in the building.

Figure 3.8 shows a typical layout of a grid connected system. PV modules are typically 12V DC although 24V DC cells are available. The inverters, which convert DC current to AC (120/240V) current, typically require a 48V DC input. The PV modules can be wired in series to achieve the 48V DC requirement. Additional PV modules are wired in parallel to increase the power input.

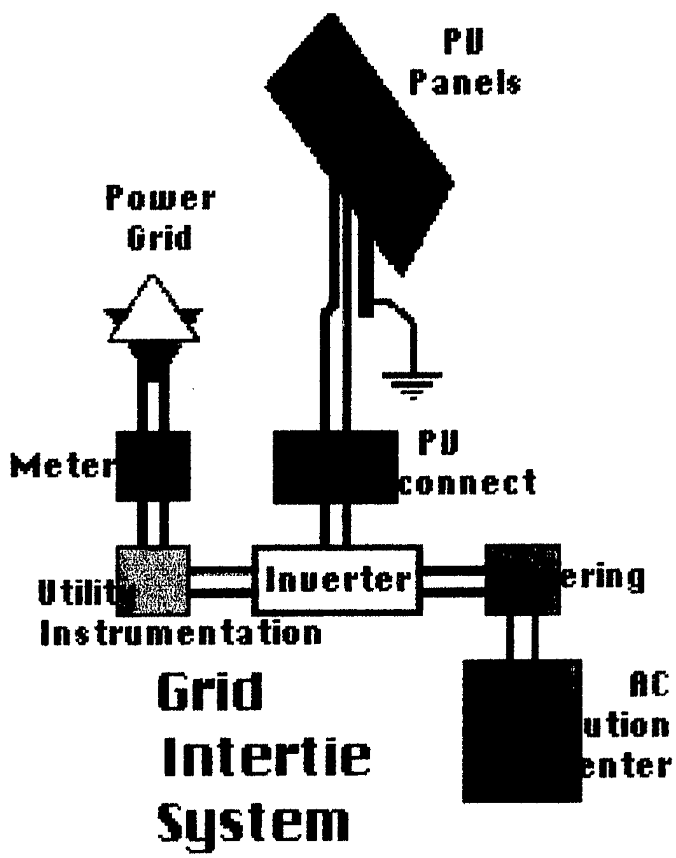


Figure 3.8 Schematic of a grid connected PV system

3.5 Cost

Over the last 20 years, the cost of PV systems has steadily declined in cost while performance, efficiency, and versatility has increased. Ironically, PV's popularity has pushed demand to record levels so that the cost has actually increased in some instances. A typical system costs between \$6 to \$20 per watt depending on the complexity of the system. The following show recent going rates for the rated system and the cost includes material and installation:

Size of system	Cost
800 W	\$ 4,200
1.35 KW	\$11,500
4.35 KW	\$35,000

The cost of PV power is still relatively high in comparison to the cost of power obtained from the grid. Taking the PV system lifecycle into consideration, the cost is about 25¢ per KWh versus 7 to 11¢ per KWh from the power company. The gap is less overseas where power is more expensive. As an example, Japan's and Germany's cost of electricity is about 20¢ and 18¢ per KWh, respectively. Consequently, there is a more widespread application of PV technology overseas. However, when tax breaks and government and utility company subsidies are factored in, the cost of PV systems may be more appealing in the U.S. As with any equipment, PV modules and components will break down over time. Current modules on the market have at least a 20 year warranty making it competitive with roofing materials. However, the support power electronics has had a bumpy start in reliability (2-15 life span) but is steadily getting better.

CHAPTER FOUR
ENERGY CONSERVATION TIPS FOR OPERATION AND MAINTENANCE

4.1 Cooling and Heating Tips

- Set the thermostat as high as comfortably possible in the summer and as low as comfortably possible in the winter. The less difference between the indoor and outdoor temperatures, the lower the overall cooling bill will be.
- Keep the temperature fairly constant, as frequent changes will utilize more energy. Setting back the temperature at night, however, with a programmable thermostat is recommended.
- Don't set the thermostat at a colder or warmer setting than normal when the heating or air conditioning unit is turned on. It will not cool or heat the building any faster and could result in excessive cooling or heating and, therefore, unnecessary expense.
- If a building will be vacant for a week of more, the thermostat temperature could be raised during the summer and lowered during the winter. However, raising or lowering the temperature when the building is vacant for a day or two is not advised as it could cost more money to bring it back to the desired temperature.
- Clean or replace the filters on furnaces or air conditioners once a month or as needed.
- Use kitchen, bath, and other ventilating fans wisely; in just 1 hour, these fans can pull out a house full of warmed or cooled air. Turn fans off as soon as they have done the job.
- During the heating season, keep the draperies and shades on the south-facing windows open during the day to allow sunlight to enter the home and closed at night. During the cooling season, keep the window coverings closed during the day to prevent solar gain.

- Close an unoccupied room that is isolated from the rest of the building, such as in a corner, and turn off the heating or cooling for that room or zone. However, do not turn the heating or cooling off if it adversely affects the rest of the system.
- Check the ducts for air leaks.
- Clean and lubricate the fan motor annually to ensure it is operating properly and provide the required airflow. Check the fan speed at the same time. Incorrect pulley settings, loose fan belts, or incorrect motor speeds cause the unit to operate inefficiently.
- Protect outdoor units from high winds, which reduces the unit's efficiency, so that the wind does not circulate over the coils. Also, keep the weeds, grass and other obstructions from blocking the airflow around the outside unit.
- Whole-house fans help cool the home by pulling cool air through the house and exhausting warm air through the attic. They are effective when operated at night and when the outside air is cooler than the inside.
- Consider using an interior fan in conjunction with the window air conditioner to spread the cooled air more effectively through the building without greatly increasing power use.
- Don't place lamps, TV sets, or other warm objects near the thermostat as they can the air conditioner to run longer than necessary.
- Plant trees or shrubs to shade air-conditioning units but not to block the airflow. A unit operating in the shade uses as much as 10% less electricity than the same one operating in the sun.

- Inspect and clean both the outdoor and indoor coils. Dirt build up on the indoor coils is the single most common cause of poor efficiency.
- Check the refrigerant charge. The system will not work efficiently if it is undercharged or overcharged.
- Reduce cooling loads during day by delaying heat-generating activities, such as dishwashing, until the evenings when it is cooler.
- Improve the efficiency of central chiller units by reducing scale, fouling, and biological growth and installing variable speed chiller drives.
- Clean warm-air registers, baseboard heaters, and radiators as needed; make sure they're not block by furniture, carpeting, or drapes.
- Bleed trapped air from hot-water radiators once or twice a season.
- Place heat-resistant radiator reflectors between exterior walls and the radiators.
- Oil-fired boilers should be professionally cleaned and tuned once a year. Gas-fired equipment needs to be checked every other year.

4.2 Indoor Lighting Tips

- Turn off the lights in any room that is unoccupied. Consider installing timers, photo cells, or occupancy sensors to automatically turn the lights on or off.
- Install 4-foot fluorescent fixtures with reflectors and electronic ballasts for the workroom, garage, and laundry areas.
- Consider using 4-watt mini-fluorescent or electro-luminescent night lights instead of their incandescent counterparts.
- Use compact fluorescent lights in all the portable table and floor lamps.

- For halogen lamps, consider replacing them with compact fluorescent torchieres. Compact fluorescent torchieres use 60% to 80% less energy and can produce more lumens than the halogen tochieres.[26] Also, the compact fluorescent torchieres generate only a fraction of the heat than that of halogen lamps as illustrated in figure 4.1.

Figure 4.1

4.3 Window Tips

- Install white window shades, drapes, or blinds to reflect solar heat away from the building.
- Close curtains and blinds on the south and west facing windows during the days of cooling season. Open them during the days of the heating season.

- Consider installing awnings on the south and west facing windows to provide shade during the cooling season. Remove them during the heating season to take advantage of the solar gain.
- Apply sun-control or other reflective films on south-facing windows to reduce solar gain in warm climates.
- Install storm windows with low-e coatings to reduce heat loss in cold climates.
- Repair and weatherize all windows if necessary.
- Install tight-fitting, insulating window shades on windows that feel drafty.
- Keep the windows clean to maximize the solar gain during the heating season.

4.4 Water Heating and Conservation Tips

- Repair leaky faucets promptly. A leaky faucet can waste gallons of water in a short period.
- Replace an inefficient water heater with a new energy efficient one. While it may be more expensive initially, the cost will be recouped over the service life of the unit.
- Install nonaerating low-flow faucets and showerheats.
- Lower the thermostat of the water heater to 120 or 115 °F. Each 10-degree reduction in Fahrenheit will reduce energy usage by 13%.
- Consider installing a solar water heater in warm and sunny climates.
- Taking showers uses less water than baths. A typical bath uses 15 to 25 gallons of hot water but a five-minute shower only uses 10 gallons.
- Consider the installation of a drain water waste heat recovery system.
- Insulate the electric hot water storage tank and pipes as shown in figure 4.2.

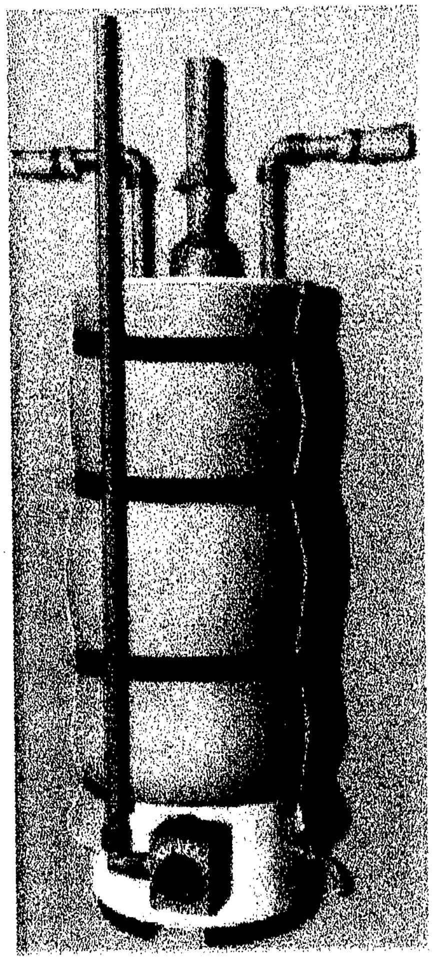


Figure 4.2

4.5 Laundry Tips

- Since heating the water in washers account for 85-90% of the energy demand,[27] minimizing hot water use is an easy way to reduce energy usage. Wash laundry in cold water whenever possible and always use cold water for the rinse cycle. Warm or hot water in the rinse cycle does not make clothes any cleaner. Colder water is easier on the clothes and makes them last longer.
- Wash and dry full loads but do not overload them. If a small load have to be washed, use the lower water-level setting.

- Locate the washing machine close to the hot water source, if possible, to reduce heat loss in long pipe runs. Insulate all exposed pipes.
- Don't use too much detergent as it can make the machine work harder and use more energy.
- Locate the dryer in a heated space. Putting it in a cold or damp area will make it work harder and less efficiently.
- Dry towels and heavier cottons in a separate load from lighter weight clothes.
- Don't over dry clothes. Use the machine's moisture sensor if it comes with one.
- Clean the lint filter in the dryer after every load to improve air circulation.
- Use the cool down cycle to allow the clothes to finish drying using the residual heat in the dryer.
- Periodically clean the dryer vent to make sure it is not blocked.
- Use the straightest and shortest metal duct available. Flexible vinyl ducts restrict airflow, can be crushed, and may not withstand the dryer's high temperature.
- Make sure the outside exhaust dryer vent closes properly to keep the outside air from leaking in. This will reduce the heating and cooling bills.
- Dry two or more loads at a time to take advantage of the dryer's retained heat.

CHAPTER FIVE
ENERGY EFFICIENT PROGRAMS

5.1 The Energy Star Buildings and Green Lights Program

The Environmental Protection Agency started the voluntary Green Lights program in 1990 to induce businesses to sign up to install energy efficient lighting and reduce pollution. After six years, the highly successful program had 2400 participants or partners who had reduced harmful emissions by almost one billion pounds and saved \$254 million per year.[28] The Energy Star Buildings program began in 1995 as an expansion of the Green Lights program. The Green Lights upgrade became the first step in the new program. The Energy Star Buildings and Green Lights program expands energy efficiency to the entire building. The program is comprised of 5 stages as listed below.

Stage 1: Green Lights – Implement Green Lights upgrades.

Stage 2: Building Tune-Up – Perform building tune-up and implement preventive maintenance and training programs.

Stage 3: Load Reductions – Install profitable window and roofing upgrades.

Stage 4: HVAC Distribution System Upgrades – Install energy efficient motors and variable speed drives downsized to new loads (with appropriate safety margins).

Stage 5: HVAC Plant Upgrades – Upgrade or replace plant with downsized, high efficiency equipment.

The concept behind the five-stage process is to make the energy saving steps more effective by implementing an orderly approach. Since changing one aspect of the building will affect the other, this will provide an integrated approach to reducing energy usage. The program's goal is to recruit 17.1 billion square feet or 17% of U.S. commercial and industrial space into the program by the year 2000. So far, 300 partners have signed up for the new program, which have saved them $326 million and reduced carbon dioxide emissions by 6.1 billion pounds each year. Typically, a building could save 30-50% in energy costs when the program is fully implemented.[29]

5.2 The Energy Star Buildings Allies Program

The EPA also created the Energy Star Buildings Allies program, which is an offshoot of the Energy Star Buildings and Green Lights program. It is intended to attract industrial and commercial organizations that manufacture, distribute, or provide energy services. Once an "ally" signs up for the program, the EPA will conduct a kickoff meeting, add the company to the Ally Services and Products Directory, and provide information, analytical software tools, workshops, and training. The ally will be authorized to use the Energy Star Buildings logo under set guidelines and be responsible to promote, publicize and recruit others into the program. Also, the ally agrees to be a partner in the Energy Star Buildings and Green Lights program and implement the five-stage process.

5.3 Energy Star Labeled Products

The Energy Star Labeled Products is joint effort between the U.S. Department of Energy and Environmental Protection Agency designed to help consumers identify energy-efficient appliances and products, and help protect the environment. It is a voluntary partnership between the government and the manufacturers. By joining this program, manufacturers produce products that meet the EPA Energy Star guidelines for energy efficiency, and can use the Energy Star label on the product. Figure 5.1 shows the Energy Star logo. The manufacturers themselves, not the EPA, test the products to ensure they meet the EPA's specifications. The list of products in the Energy Star program is extensive and includes windows, heating and cooling products, transformers, exit signs, light fixtures, home electronics and office equipment. Each year, this program saves save over $1 billion in energy costs while also cutting air pollution.[30]

Figure 5.1

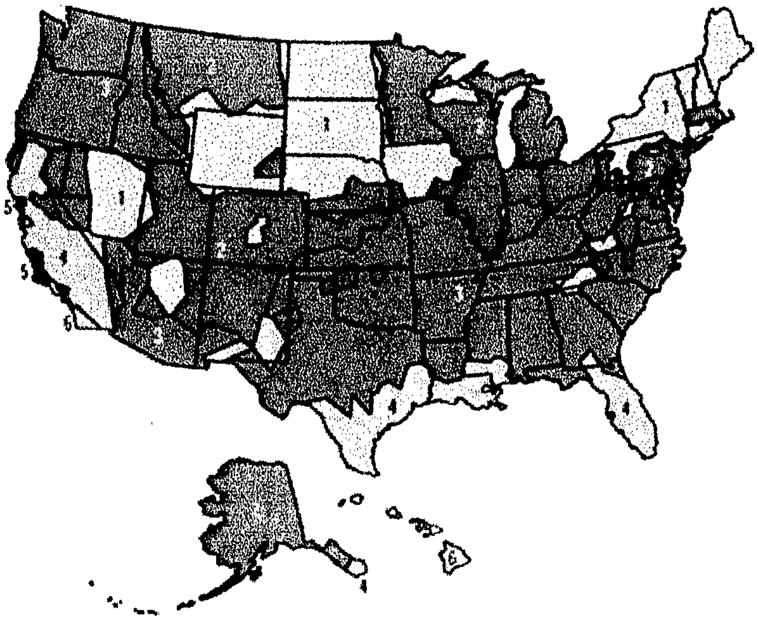
CONCLUSION

There are many advantages to energy efficient buildings. Besides lower life cycle costs, energy efficient buildings offer owners a more comfortable and productive environment.[31] Reduced energy usage also helps the environment by reducing the emission of greenhouse gases and extends the life of non-renewable energy resources for future generations.

PV systems have a bright future ahead of it as evident by the current high demand for them. As we use up the world's resource of fossil fuels, there will be a more reliance of solar power in the coming years. Also as the price of PV systems continual to decline, PV power may one day cost less than power from the grid. The government and industry has also exhibited leadership in the development of PV technology. In 1997, President Clinton reveal an initiative that set a goal of 100 million solar roofs by 2010. Hopefully, his intiative will become a reality as we move into the next century.

Much progress in energy efficiency and conservation has taken place since the energy crisis of the 1970's, but greater efficiency can still be achieved. With the continual development of energy efficient products and help from organizations and programs like the EPA's Energy Star Buildings and Green Lights Program, the world can be a greener and brighter place to live.

U.S. Department of Energy Recommended Total R-Values for Existing Houses in Eight Insulation Zones [a]



					Ceiling						Basement	
Insulation zone	Gas	Heat pump	Fuel oil	Electric furnace	Attic	Cathedral	Wall[A]	Floor	Crawl space[B]	Slab edge	Interior	Exterior
1	✓	✓	✓		R-49	R-38	R-18	R-25	R-19	R-8	R-11	R-10
1				✓	R-49	R-60	R-28	R-25	R-19	R-8	R-19	R-15
2	✓	✓	✓		R-49	R-38	R-18	R-25	R-19	R-8	R-11	R-10
2				✓	R-49	R-38	R-22	R-25	R-19	R-8	R-19	R-15
3	✓	✓	✓	✓	R-49	R-38	R-18	R-25	R-19	R-8	R-11	R-10
4	✓	✓	✓		R-38	R-38	R-13	R-13	R-19	R-4	R-11	R-4
4				✓	R-49	R-38	R-18	R-25	R-19	R-8	R-11	R-10
5	✓				R-38	R-30	R-13	R-11	R-13	R-4	R-11	R-4
5		✓	✓		R-38	R-38	R-13	R-13	R-19	R-4	R-11	R-4
5				✓	R-49	R-38	R-18	R-25	R-19	R-8	R-11	R-10
6	✓				R-22	R-22	R-11	R-11	R-11	(C)	R-11	R-4
6		✓	✓		R-38	R-30	R-13	R-11	R-13	R-4	R-11	R-4
6				✓	R-49	R-38	R-18	R-25	R-19	R-8	R-11	R-10

(A) R-18, R-22, and R-28 exterior wall systems can be achieved by either cavity insulation or cavity insulation with insulating sheathing.
For 2 in x 4 in walls, use either 3-1/2-in thick R-15 or 3-1/2-in thick R-13 fiber glass insulation with insulating sheathing.
For 2 in x 6 in walls, use either 5-1/2-in thick R-21 or 6-1/4-in thick R-19 fiber glass insulation.

(B) Insulate crawl space walls only if the crawl space is dry all year, the floor above is not insulated, and all ventilation to the crawl space is blocked.
A vapor retarder (e.g., 4- or 6-mil polyethylene film) should be installed on the ground to reduce moisture migration into the crawl space.

(C) No slab edge insulation is recommended.

NOTE: For more information, see: Department of Energy Insulation Fact Sheet (D.O.E./CE-0180). Energy Efficiency and Renewable Energy Clearinghouse, P.O. Box 3048, Merrifield, VA 22116; phone: (800) 363-3732; www.ornl.gov/roofs+walls/insulation/ins_11.html or contact Owens Corning, (800) GET-PINK (800-438-7465), www.owenscorning.com

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